ANALYSIS OF CLOUD CHAMBER PHOTOGRAPHS

Typical Cloud Chamber Configuration

The cloud chamber, invented in 1907 by C.T.R. Wilson, is one of the most useful instruments in nuclear physics. It allows us to observe the trajectory of a charged atomic particle and to determine some of its important properties such as mass and momentum. Wilson, interested in the fogs of the British Highlands, experimented with artificial fog production. He found that if water vapor confined in a closed region is suddenly expanded it may be cooled sufficiently so that water will condense on any dust particles present. If the region is dust-free, the vapor cannot readily condense, and a supersaturated water vapor can be produced. Water molecules in such an enclosure which are ionized by an entering charged particle may serve as nuclei of condensation. The path of the ionizing particle then becomes a trail of tiny water droplets which are easily seen and photographed.

Typically, a cloud chamber consists of a tightly enclosed dust-free space containing a saturated dust-free vapor. If the chamber is suddenly expanded adiabatically the vapor can become supersaturated.[1] If a charged particle passes through the chamber, ions are formed along its path and subsequent condensation results in a trail of droplets. At this instant the chamber is usually illuminated and two or three cameras stereoscopically photograph the trail. Cloud chamber photographs are particularly useful in studying collisions between particles. Also, a charged particle entering a cloud chamber which is mounted in a unidirectional magnetic field will be deflected and follow a curved path. The momentum of the charged particle is then determined by the curvature of its path. This method led to the discovery of the positron in 1932 by C.D. Anderson.

A cloud chamber frequently contains several parallel metal plates which serve to stop an entering particle. Much information can be deduced about the particle from its trajectory and the cloud chamber geometry. Such an event is the major topic of this note. In particular, a k-meson which is stopped by one of the plates will decay into a μ-meson and a neutrino. Both offshoot particles receive kinetic energy during the decay process and travel in the cloud chamber until they are stopped by the brass plates. If the total distance traversed through the brass

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1. A gas expands adiabatically when no heat is transferred to or from the gas during expansion.

plates by the μ-meson is known, the mass of the k-meson may be reliably estimated. Stereoscopic photographs of the decay process may be interpreted to determine the total brass plate penetration. The plate penetration may easily be related to the k-meson mass by some simple equations and graphs which are based on the theory of particle mechanics. This experiment serves a useful purpose by allowing the physicist to compare the k-meson mass to the mass of an electron.

Cloud Chamber Photographs

Figure 1 contains elevation and plan views of the cloud chamber and cameras. This arrangement was used in taking the photographs of a typical decay process which appears in Figures 2 and 3. From these photographs the true length of the μ-meson penetration through the brass plates may be determined. The apparent points of entrance and exit of a particle through a brass plate, from the photographs of Figures 2 and 3, were used to locate the points of intersection of the particle path with the surface of the brass plates shown in Figure 4. The path within any brass plate is assumed to be linear and to extend from the point of entrance to the point of exit. If such points of intersection are found for all path segments, their true lengths may be found by conventional means.

The neutrino does not form a droplet path because it has no rest mass[1] or electrical charge. The point of k-meson decay is obtained from theoretical considerations which are beyond the scope of this case. The μ-meson is completely absorbed in the last brass plate along its path. The final position of the μ-meson is not evident from the photographs. Thus, the total true length of particle path through the brass plates is not known exactly. The photographs do, however, provide means of imposing limits on this total distance. The lower limit is obtained by assuming that final absorption of the μ-meson occurs just after it enters the last plate. The upper limit follows by assuming that the μ-meson is absorbed just before exiting from the last plate along its path. In locating the extreme points of absorption (shown in Figure 4) we assume that the particle paths are not refracted as they cross the brass plate boundaries.

Cloud Chamber Mechanics

If a particle, say a k-meson, of rest mass M_0 decays into two other particles, say a μ-meson and a neutrino, of rest masses M_1 and M_2, the total energy of the parent particle must equal the total energy of the two offshoot particles. That is

$$M_0c^2 = M_1c^2 + M_2c^2 + E_1 + E_2 \qquad (1)$$

where c is the velocity of light and E_1 and E_2 are the kinetic energies of particles 1 and 2 respectively. The theory of particle mechanics also requires that the relativistic momenta of the two offshoot particles be equal. Upon equating the relativisitc momentum of each offshoot particle,

1. Due to effects which are explained by the theory of relativity ~~the mass~~ of any particle will increase as its velocity increases. When a particle is stationary its mass is referred to as a rest mass.

we obtain

$$\frac{E_1}{c}\sqrt{1 + \frac{2M_1c^2}{E_1}} = \frac{E_2}{c}\sqrt{1 + \frac{2M_2c^2}{E_2}} \tag{2}$$

Elimination of E_2 between equations (1) and (2) yields

$$M_0c^2 = E_1 + M_1c^2 + \sqrt{(E_1 + M_1c^2)^2 - (M_1c^2)^2 - (M_2c^2)^2} \tag{3}$$

The neutrino has zero rest mass and the mass energy, M_1c^2, of a μ-meson is 105.7 Mev.[1] Using these facts for the decay of a k-meson into one neutrino and one μ-meson equation (3) becomes

$$M_0c^2 = E_1 + M_1c^2 + \sqrt{E_1^2 + 211.4E_1} \tag{4}$$

where M_0 and M_1 are expressed in grams and E_1 is expressed in ergs.

The kinetic energy, E_1, of the μ-meson is obtained from its true length of brass plate penetration and a smooth graph of the data given in Table 1.

PENETRATION Cm	ENERGY Mev
7.28	123.95
8.18	135.22
9.09	146.48
10.00	157.75
10.91	169.02
11.82	180.20

TABLE 1 - Penetration Energy Data for a μ-meson

Bounding values for the k-meson mass can be obtained from the calculated values of E_1 and the values of constants taken from Table 2.

CONSTANT	VALUE	UNITS
Speed of light	2.99×10^{10}	cm/sec
Erg	1	$gm/cm^2/sec^2$
Brass plate thickness	1.279	cm

TABLE 2 - Useful Constants

1. An abbreviation for one million electron-volts. An electron-volt is a unit of energy equal to 1.60×10^{-12} ergs.

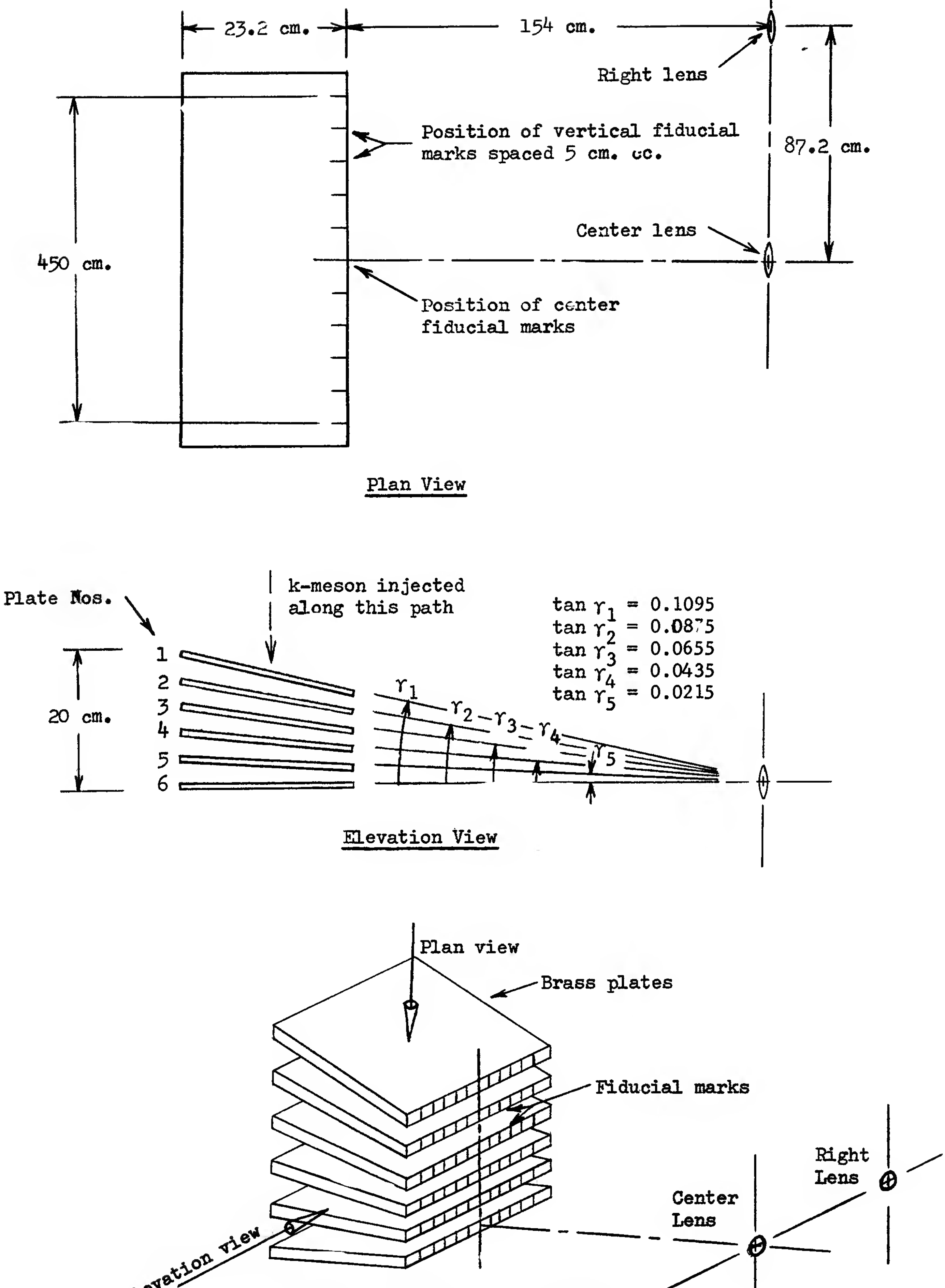


Figure 1 — Camera Configuration

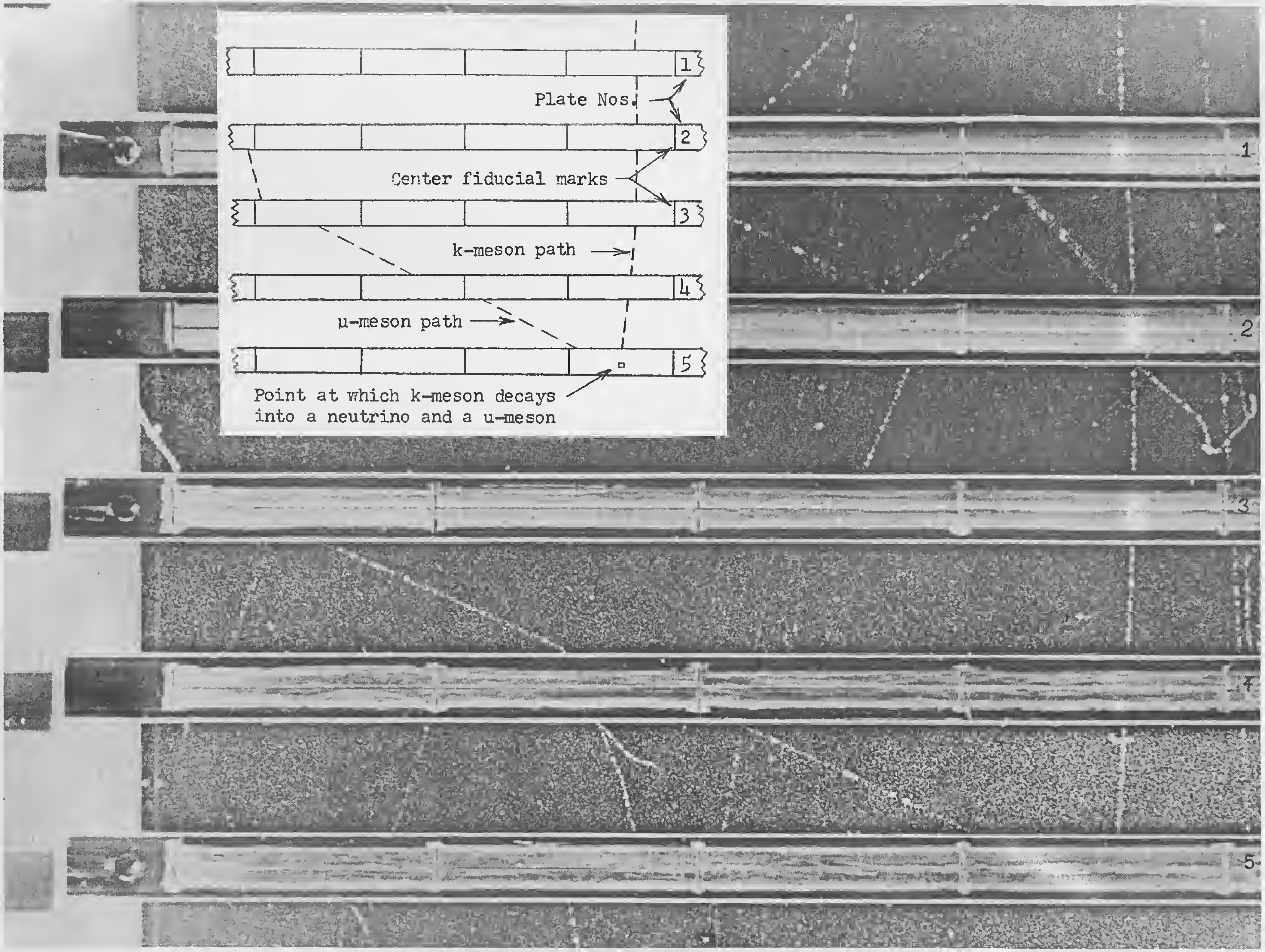


Figure 2 - Photograph From Center Lens

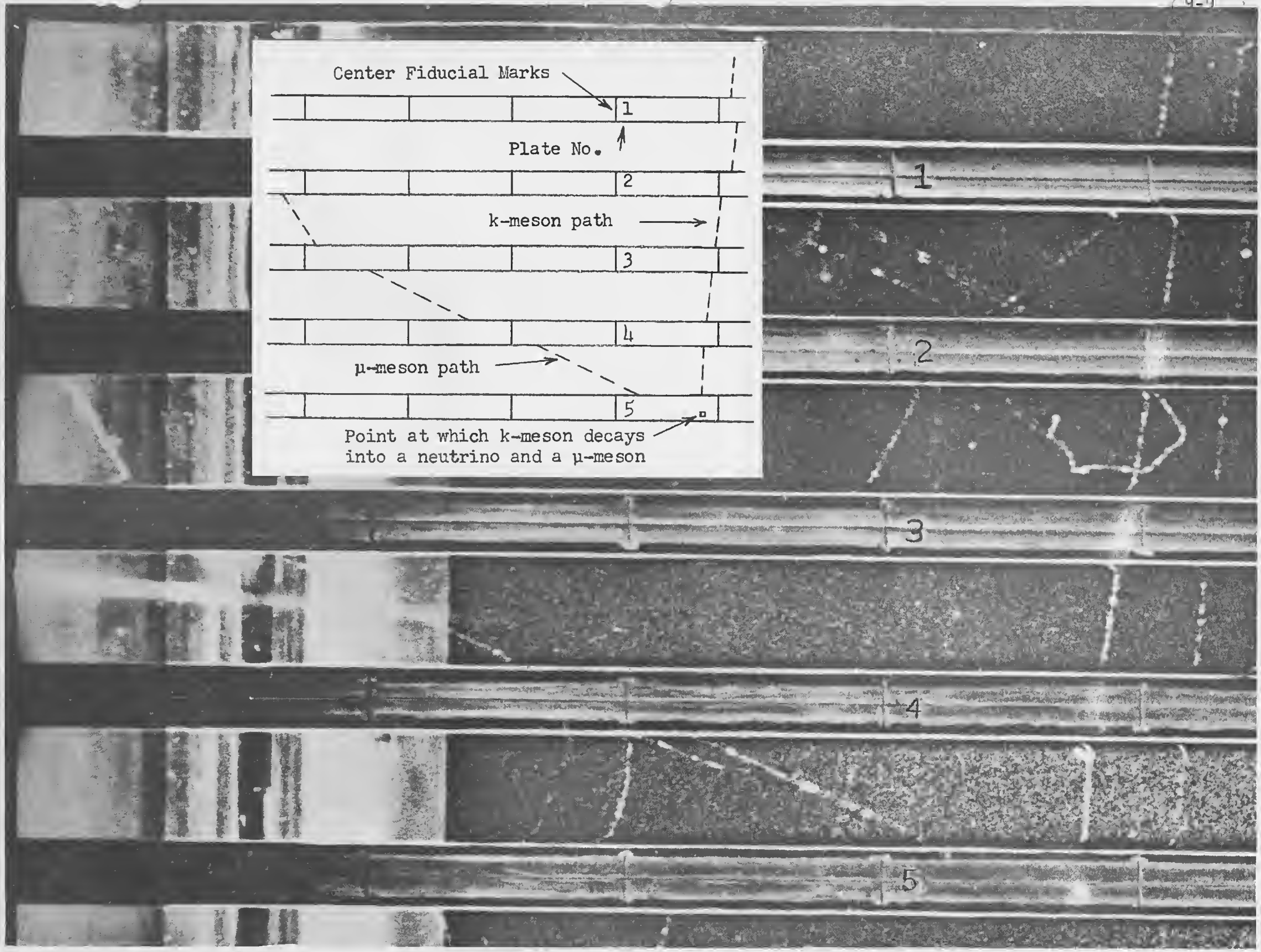


Figure 3 - Photograph From Right Lens

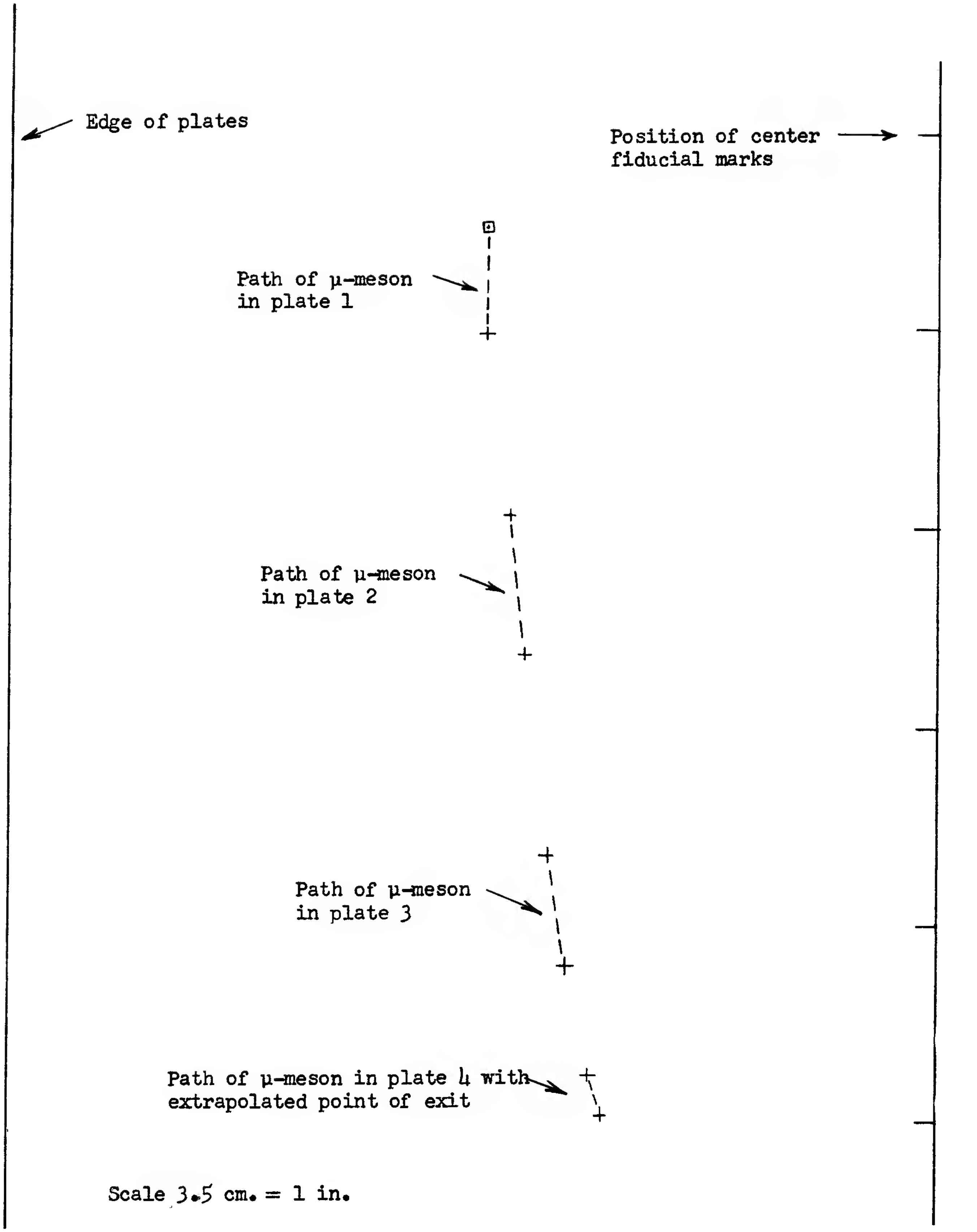
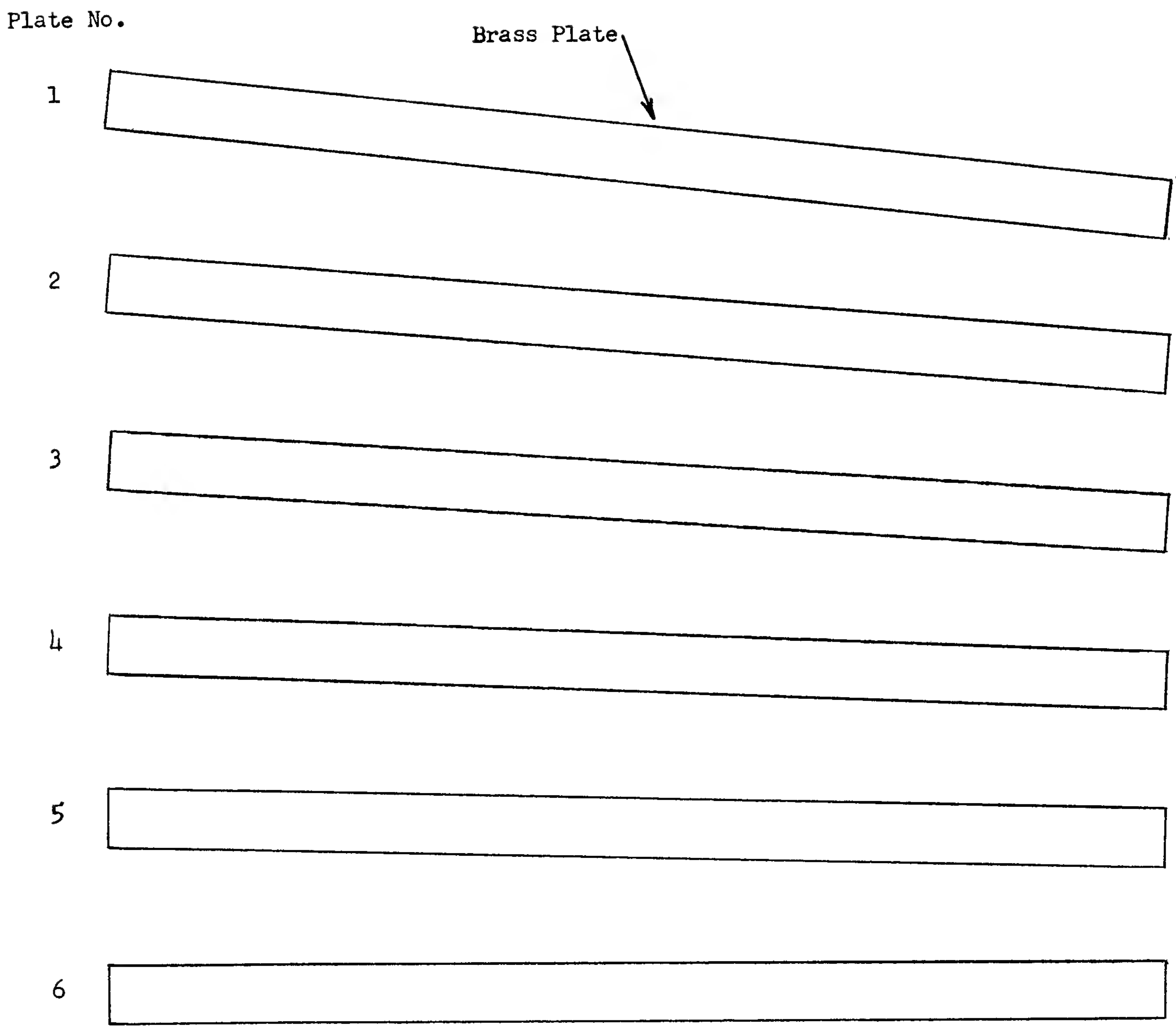


Figure 4 - Plan View of Cloud Chamber and μ-meson Path



Scale 3.5 cm. = 1 in.

Figure 5 - Elevation View of Cloud Chamber Plates